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Steel Fiber Concrete Mixture Workability

G.A. Pikus*

South Ural State University, 76, Lenin Avenue, Chelyabinsk, 454080, The Russian Federation

Abstract

The article provides an overview of existing parameters of concrete mixture workability estimates for steel fiber concrete. The study shows that the standard concrete workability parameters such as mobility, stiffness, spread, viscosity may not be used for steel fiber concrete mixtures. We propose evaluation of the steel fiber-concrete mixture workability using the dimensionless coefficient, which is a stress magnitude for the steel fiber concrete mixture at the normal stress unit value. Using of a standard laboratory tool for a single plane shear soil tests with larger rings is recommended for testing. The resulting values for the dimensionless coefficient are approximated by mathematical relations with a high reproducibility. The proposed mathematical model of the dimensionless coefficient provides a clear determination of the steel fiber concrete mixture workability.

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Keywords: workability; steel fiber concrete; concrete mixture stiffness; concrete mixture mobility; shear stress.

1. Introduction

Widespread using the steel fiber concrete mixtures in construction shows that the current standards do not provide the effective concrete workability estimating. The current construction norms may be applied only to control the unreinforced concrete mixes workability and evaluate it using mobility, stiffness or spreading parameters [1-6].

* Corresponding author. Tel.: +7-905-839-0956; fax: +7-351-267-9183.
E-mail address: pikusga@susu.ru

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2. Current parameters review

Using the parameters for steel fiber concrete mixture workability is not effective as steel fiber, being randomly oriented in the concrete mixture, produces a space frame that takes the loads from different directions through aggregative forces.

As a result, when estimating the mobility, the fiber frame resists to static displacement of mixture components relative to each other, and for mixtures with high content of steel fiber no slump occurs.

When estimating steel fiber concrete mixture stiffness, the mixture loses its shape rapidly at the initial stage of vibration action, but at the later stage, the damage rate slows down significantly [7]. This effect can be explained by the rapid damaging the unstable fiber frame at the initial stage, accompanied by fiber reorientation. It leads to increasing the internal friction forces and grip to cement paste; to compactness of aggregate and fiber particles networks and finally to their mechanical interlocking.

Additionally, the study [8] proves that the identical stiffnesses with different fiber reinforcement percentage (μ) can be obtained in mixtures with fibers of different ratios of length to diameter (*l/d*) (Fig. 1a). For example, eight seconds stiffness can be obtained by three percent fiber *l/d* = 150, 6% fiber with *l/d* = 100% and 9% fiber with *l/d* = 66.

In some cases, the authors offer to estimate mortar and concrete mixture workability by viscosity parameter. However, this parameter is more applicable for Newtonian liquids whose viscosity changes only with changes in temperature. Concrete mixture viscosity may vary several-fold even at a constant temperature, depending on the value of the external forces acting on the mixture. Only high-workability concrete mixtures may be regarded as Newtonian liquids [9], and fiber reinforcement, due to a sharp decrease and sometimes even complete extinction of mobility symptoms, complicates the specification of steel fiber mixture workability by viscosity parameter.

Furthermore, concrete mixture viscosity depends on the aggregate properties, and combined with the stiffness parameter, does not provide clear evaluating the mixture workability properties [10]. Thus, depending on the mixture composition, the same stiffness may provide different viscosities (Fig. 1b).

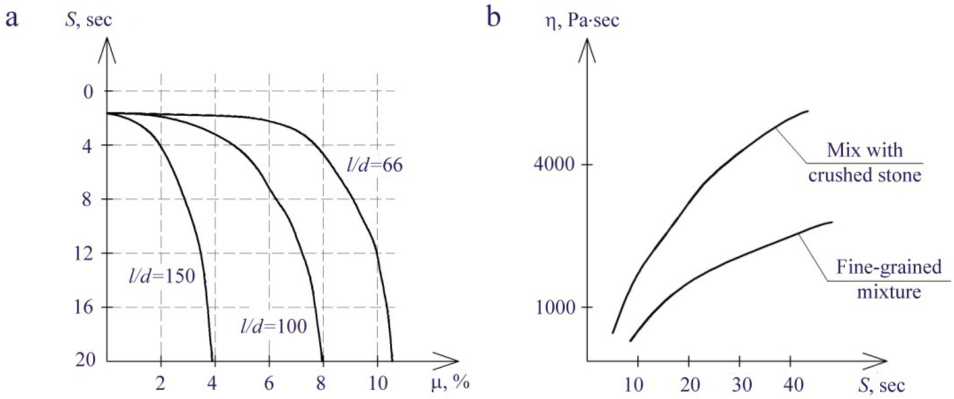

Fig. 1. (a) changes in steel fiber concrete mixture stiffness related to fiber reinforcement percentage by weight; (b) viscosity η and stiffness S relations depended on different mixture constituents.

The need to find a new rheological parameter, applicable to evaluating steel fiber-reinforced concrete mixture workability is discussed in [11-13], though in some cases, even in the current regulatory papers the requirement for evaluating steel fiber concrete workability using mobility is given [14-19].

3. Experimental study

A series of experiments searching the current and prospective evaluation criteria for steel fiber concrete mixture workability was carried out in the laboratory. In experiments we used the following mixture composition per 1 m^3:

cement – 420 kg, sand – 620 kg, crushed stone (fraction 5-20) – 1190 kg, water – 212 L (W/C = 0,5). The fiber is cut of a 40 mm long, 0,6 mm nominal diameter (*l/d* = 66) steel sheet. Superplasticizer C-3, accounting for 1,75% of the cement weight, was used as an admixture.

Table 1 shows the results of workability standard estimation (mobility and stiffness) for these mixtures composition, which clearly indicates they may not be used for steel fiber concrete mixtures.

Table 1. Average values for workability parameters based on GOST Standard for experimental mixtures.

Admixture content, (A), %	Steel fiber reinforcement percentage, (μ), %	Parameter	
		Mobility,cm	Stiffness, sec
0	0	–	11
0	0,75	–	31
0	1,5	–	60
1,75	0	5	–
1,75	0,75	2	22
1,75	1,5	–	not determined

Our studies show that the dimensionless coefficient may be used as an optimal parameter for estimating steel fiber concrete mixtures workability

$$k = tg\varphi + \tau_0 \qquad (1)$$

where φ is the angle of steel fiber concrete mixture internal friction, deg.;

τ_o is the specific cohesion of steel concrete mixture, kg/cm^2.

The physical meaning for k coefficient is the value for steel fiber concrete mixture shear stress at a unit quantity of normal stress.

Determining the dimensionless k coefficient was performed using a standard laboratory installation for direct shear ground testing (Fig. 2).

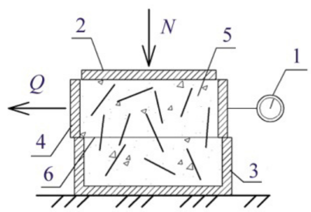

Fig. 2. The installation diagram for determining the dimensionless k coefficient. 1 - dial gauge, 2 - transpierced stamp, 3 - lower slewing ring 4 – upper moving ring, 5 - steel fiber concrete mixture, 6 - shear area.

The steel fiber concrete mixture is placed into a cylindrical vessel consisting of a top moving ring and a bearing part firmly fixed to the testing unit.

The transpierced stamp, providing uniform pressure put by tightening weight *N* is set on the mixture top. The acting *Q* force displaces the top ring that shears some steel fiber concrete mixture along the shift area. The steel ring displacement is measured with a dial gauge.

Lest the mixture be homogeneous and the dispersed reinforcement influence not be local, the sizes of the vessel for the mixture placing should be comparable to the fiber length and preferably exceed it. Thus, the unit standard rings were replaced by the larger ones with diameter of 118 mm and depth of 30 mm for the lower ring and 65 mm for the upper ring. In the experiments, the values of shear stresses were determined by the normal stresses shear when the top ring comes up to 4 mm displacement. The decrease in shear area due to the displacement of the top steel ring can be neglected.

In the experiment, the mixture is gradually loaded with tightening weights N to provide the increase of the required shear Q force. The shear stresses values τ or their values when the top ring comes up to 4 mm displacement from the normal stresses σ are determined according to the empirical data (Table 2).

Table 2. Shear stresses values at corresponding normal stresses.

Reinforcement coefficient (μ), %	Normal stresses (σ), kg/cm^2	Shear (τ), kg/cm^2	
		Admixture 1,75%	Admixture 0%
0	0,00412	0,0152	0,0150
0	0,00869	0,0186	0,0242
0	0,01280	0,0225	0,0306
0	0,01730	0,0270	0,0343
0,75	0,00412	0,0178	0,0183
0,75	0,00869	0,0168	0,0278
0,75	0,01280	0,0227	0,0314
0,75	0,01730	0,0302	0,0399
1,5	0,00412	0,0169	0,0225
1,5	0,00869	0,0204	0,0288
1,5	0,01280	0,0250	0,0377
1,5	0,01730	0,0302	0,0445

For conventional concrete mixtures (without fiber reinforcement) dimensionless k coefficient depends on the admixture content and mixture constituents. For steel fiber concrete mixtures, all other variables to be constant, its behavior depends on the percentage of fiber reinforcement, the type of a fiber and its properties.

The results of the experimental studying various mixture compositions are given in Table 3. It shows a clear correlation between the input parameters and the k response

Table 3. The research results for determining the dimensionless k coefficient.

Admixture content, (A), %	Steel fiber reinforcement percentage, (μ), %	φ, deg.	τ_o, kg/cm^2	k
0	0	55,8	0,0102	1,484
0	0,75	57,5	0,0125	1,584
0	1,5	59,7	0,0150	1,728
1,75	0	41,9	0,0112	0,911
1,75	0,75	44,5	0,0113	0,994
1,75	1,5	45,5	0,0122	1,031

The values obtained were approximated by functions:

– for mixtures containing no admixtures (convergence is 0,9893)

$$k = 0{,}1629\mu + 1{,}4765 \tag{2}$$

– for mixtures containing some admixtures (convergence is 0,9509)

$$k = 0{,}0798\mu + 0{,}9189\,. \tag{3}$$

It should be borne in mind that the correlations are obtained for mixtures containing steel sheet fiber with concrete geometric parameters of "Magnitogorsk Fibra-Stroy" plant.

4. Conclusions

Thus, the proposed mathematical model provides high reproducibility and unique determining steel fiber concrete mixture workability, and the standard testing equipment should be used to determine the dimensionless coefficient.

At present, the results obtained are used to evaluate pressure produced by steel fiber concrete mixtures on the vertical formwork systems [20]. The study also proves using dimensionless k coefficient as a relevant criterion for the steel fiber concrete mixture workability.

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